Dynamics of Exciton Transport and Recombination in InAlGaAs Quantum Dots

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We report on excitonic transport and recombination in InAlGaAs/AlGaAs structures containing quantum dots. Such quantum dots emit bright, red light. Intensity was high enough to make time resolved micro luminescence spectroscopy and determine lifetimes of individual quantum dots.

The structures were grown by solid-source MBE on GaAs (001) substrates. The barriers were made of ternary alloy $Al_{0.75}Ga_{0.25}As$ and the quantum dots were formed of quaternary alloy $In_{1-x}(Al_yGa_{1-y})_xAs$ (x =0.6, y=0.75) in Stranski-Krastanow (S-K) growth mode at 500°C. The Al-containing alloys allow wide range bandgap and strain engineering in the III-As material system. The compositions reported here provide an in-plane compressive strain close to the minimum one required for a self-assembled S-K formation of QDs in III-As system. A series of samples was prepared at different growth rates and with different nominal coverage. Some of the samples were doped with Mn in order to compare slow and fast nonradiative decay conditions. Transmission electron microscopy and atomic force microscopy revealed that QD density was of the order of 10^{10}-10^{11} cm^{-2}.

Micro-photoluminescence (PL) was measured at temperatures T = 4 - 10 K in continuos mode excitation, with a low power, P = 50 - 500 µW. Spectral resolution of the detection was 0.15 meV. Time-resolved PL (TRPL) was excited with a third harmonic of Ti:Sapphire laser, with impulse energy of 0.4 pJ and measured with streak camera, in the temperature range 4 - 50 K. The collecting spot had diameter of about 1 µm and 3 µm for continuos and TRPL spectroscopy, respectively.

Efficient PL emission was observed in the red spectral range 1.72 – 1.92 eV (λ = 650 - 720 nm) which is close to the shortest wavelengths possible in III-As compounds. The spectra covered a broad range, however, the micro-PL measurement revealed that they consisted of many sharp lines. The widths of the lines were below spectrometer resolution.

Time evolution of single QDs emission could be observed (see Fig. 1.). Sharp, bright single dot emission lines showed relatively long lifetimes (about 0.7 – 2 ns), while a shorter average lifetime was observed for a broad emission band (about 0.3 - 0.8 ns) of unresolved lines from ensemble of weaker QDs. High brightness and long lifetime of the strong QDs suggest that either they have a lower nonradiative recombination rate or that they can capture effectively excitons tunneling between QDs. Such efficient trapping could occur if these dots had locally the lowest energy in the neighborhood of many QDs.

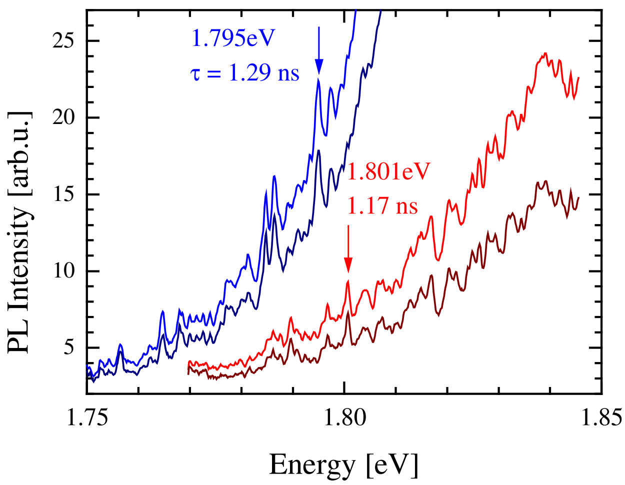

Fig. 1. Time-resolved PL of InAlGaAs/AlGaAs QDs. Spectra measured at two different time delays (0.5 ns and 1 ns) for two samples. Decay constants are indicated for selected transitions.

Analysis of the temperature dependence shows that thermally activated delocalization and excitonic transport occurs at temperatures above 20 K. This transport leads to a spectral shift of ensemble QDs emission with time. The temperature dependence of dynamics can be explained by the assumption that excitonic transport is due to tunneling between neighboring QDs facilitated by the high planar density of the QDs in the studied samples.